SOIL CLEAN-UP GUIDELINES FOR DECOMMISSIONING OF INDUSTRIAL LANDS:

BACKGROUND AND RATIONALE FOR DEVELOPMENT

MARCH 1991

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SOIL CLEAN-UP GUIDELINES FOR DECOMMISSIONING OF INDUSTRIAL LANDS: BACKGROUND AND RATIONALE FOR DEVELOPMENT

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MARCH 1991

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1 BACKGROUND

In February, 1984, the Phytotoxicology Section was requested by the Halton-Peel District Office of the MOE to provide input into the development of soil guidelines for the decommissioning of certain oil refinery lands. Proposed land uses made it desirable to have separate criteria for residential and industrial redevelopment. Monenco Consultants, on behalf of one of the oil companies, undertook a large-scale literature survey in an attempt to relate contaminant concentrations in soil to toxic effects on vegetation, animals and man. As a result of this effort, Monenco recommended site-specific soil clean-up criteria for a number of contaminants (Monenco Ontario Ltd., 1984a & 1984b).

The Phytotoxicology Section critically reviewed Monenco's proposals. In some cases, the clean-up levels suggested by Monenco were supported by information available to the Phytotoxicology Section, and were deemed acceptable to the MOE. In a number of cases, however, the recommended clean-up criteria were considered unacceptable. Most of the disagreements were resolved at a series of meetings involving the oil companies, Monenco and the MOE (Halton-Peel Office and Phytotoxicology Section staff). However, in a limited number of cases, the clean-up levels recommended by the Phytotoxicology Section were regarded as somewhat conservative by Monenco Consultants. Also, Monenco Consultants did not provide input to all of the recommended guidelines.

Subsequent to the above-described exercise, the Phytotoxicology Section was asked to recommend clean-up guidelines for additional contaminants. Provisional guidelines for these additional elements were developed, based on literature reviews. The guidelines and

provisional guidelines were reviewed and approved by the Health Studies Service, Special Studies and Services Branch of the Ministry of Labour and by the OMAF/MOE/MOH Sludge and Waste Utilization Committee. More recently, the Phytotoxicology Section was requested by the MOE Waste Management Branch to develop clean-up levels for agricultural land use. This request was brought to the attention of the Sludge and Waste Utilization Committee. It was the opinion of this Committee that the residential/parkland clean-up levels previously developed were, with minor modifications/qualifications, also suitable for application to agricultural situations.

These clean-up guidelines and provisional guidelines have been incorporated into the Waste Management Branch policy document, "Guidelines for the Decommissioning and Clean-up of Sites in Ontario", (MOE, 1989b).

2 RATIONALE FOR DEVELOPMENT

The recommended soil clean-up guidelines for industrial site decommissioning are shown in Table 1. The rationales for their development include considerations of phytotoxicity, animal health, and human health. In general, the most conservative of these considerations was used to established a residential clean-up level. Redevelopment as parkland also was felt to warrant this conservative approach, because parkland often is used by children at play, and occasionally is used for allotment gardening.

Different industrial/commercial clean-up levels (normally set at twice the residential levels) were recommended where the residential and industrial criteria were both set on the same basis (i.e. phytotoxicity or human health), but where phytotoxic or health concerns were judged to be considerably less significant in the industrial/commercial environment.

For two elements (molybdenum and selenium), residential clean-up levels were established to prevent toxicity to grazing animals, whereas a higher industrial level was established to prevent toxicity to vegetation. Where assurances can be had that land will not be used for production of animal feed (most residential situations), the animal health-based guidelines need not be applied.

Provisional clean-up guidelines recommended for four contaminants are shown in Table 2. Because knowledge of potential adverse effects of these elements in soil is generally more limited than for the Table 1 guidelines, the provisional clean-up levels were purposefully established in an even more conservative vein. The terms "guideline" and "provisional guideline" are defined in Appendix 1. A discussion of possible interactive effects (antagonistic, additive or synergistic) of soil contaminants is presented in Appendix 2. These clean-up guidelines and provisional guidelines are considered to be suitable for direct application in the majority of industrial site clean-up scenarios that may be encountered in Ontario. However, since the mobility and availability of metals in soils may be highly dependent on form of the metal, soil texture, pH and organic matter content, site-specific considerations of these parameters may reveal the suitability of different criteria. For example, where metals are known to be present in specific forms of very limited availability, higher clean-up levels may be considered. Furthermore, in researching the clean-up criteria, Monenco Consultants utilized data from studies on medium to fine textured soils (i.e. sandy soils excluded), in which mobility (availability) of metals would be lower than in coarse-textured sand (hence, metals are less likely to accumulate in sand than in clay). Therefore, it is recommended that the clean-up levels for the metals and metalloids be reduced in the case of coarse-textured (greater than 70% sand) mineral soils (less than 17% organic matter). This recommendation is reflected in the clean-up levels shown in Tables 1 and 2.

The rationales for the individual parameters are summarized below in point form. Concentrations are given as ppm (g/g), dry weight, unless otherwise indicated).

These rationales and the guideline values which were developed from them will be revised as the results of new research become available.

2.1 Soil pH

- range as generally amenable to good plant growth is pH 6-8 (i.e. slightly acidic to slightly alkaline)
- at pH < 6, availability of metals may increase such that phytotoxicity could occur even if total metal concentrations were below clean-up levels
- at pH > 8, solubility (availability) of toxic Cr VI increases markedly, and oxidation of Cr III to Cr VI may occur (Bartlett & Kimble, 1976)
- also at pH > 8, Mo and Se may be readily mobilized and taken up by fodder at levels toxic to grazing animals (Lindsay, 1972)

Recommendation: **soil pH should lie within the range of 6 to 8 for both residential and industrial re-development.**

* Note - Naturally acid soils of pH as low as 4 are common in northern boreal environments. Such acidic sites can be decommissioned without requirement for liming provided the allowable metal levels are appropriately reduced.

2.2 Arsenic (As)

- arsenic is essential to mammals and algae (Bowen, 1979) but essentiality to higher plants has not been confirmed (Kabata-Pendias and Pendias, 1984)
- the toxicity of arsenic to plants and animals is well documented, although it is not classified as a cumulative poison in man (NAS, 1977)

- the Phytotoxicology Section "upper limit of normal" arsenic guideline for urban Ontario surface soils is 20 ppm (MOE, 1989a)

- it is generally agreed that the main problem caused by excessive arsenic in soils is phytotoxicity rather than accumulation by crops of arsenic levels toxic to animals and man, because significant phytotoxic effects occur at lower arsenic levels in plants than do health effects (Jacobs et al., 1970; Peterson et al., 1981)

- arsenic levels in plant tissue reported as phytotoxic are: 5 - 20 ppm (Kabata-Pendias and Pendias, 1984); 20 ppm (Davis et al., 1978); 0.5 - 230 ppm (reported in NRCC, 1978); 3 - 10 ppm (Chaney, 1982)

- the limit set for arsenic in food crops in the U.S. is 2.6 ppm, fresh weight (U.S. Public Health Service, reported in Peterson et al. 1981), equivalent to approx. 13 to 52 ppm on a dry weight basis

- Kirkpatrick (1981) has stated that arsenic levels in fruits and vegetables above 1 ppm, fresh weight (equivalent to 5-20 ppm, dry weight, depending on moisture content) may pose a potential danger to health from long-term consumption

- the Phytotoxicology Section (unpublished results) has found average arsenic levels in fresh vegetables of 0.17 ppm (equivalent to 0.85 - 3.4 ppm, dry wt.) at average soil arsenic levels of 61 ppm

- NAS (1980) has established 50 ppm (dry wt.) arsenic as the maximum dietary concentration chronically tolerated by livestock

- phytotoxicity of arsenic in soil is dependent upon soil texture (as with most metals) and upon form of arsenic, with highly water-soluble forms of arsenic being more toxic than less soluble forms (Peterson et al., 1981)

- toxicity of soil arsenic decreases in the order: arsenite > arsenate > organic arsenicals (MSMA,CA) (Peterson et al., 1981)

- however, regardless of the form in which the arsenical is applied, it is apparently eventually oxidized and metabolized to arsenate (Woolson, 1973)

- Walsh and Keeney (1975) have established that a critical range of total arsenic in soils at which reduced crop yields may occur is 25 - 85 ppm

- a review of the literature given in NRCC (1978) generally supports a minimum total soil arsenic phytotoxic level of 25 ppm, with effects at low levels being restricted to sensitive plants such as legumes and rice

- a maximum allowable phytotoxicity-based limit of arsenic in paddy soils of 15 ppm has been proposed in Japan (cited in Kabata-Pendias and Pendias, 1984) (availability of arsenic is increased in wet (reduced) soils (Peterson et al., 1981))

- Ontario Ministry of the Environment investigations (unpublished) on former mine tailings areas have found no adverse effects on plants of 200 ppm or more of arsenic (as arsenic trioxide) in soil

- Anderson et al. (1983) recommended a maximum soil arsenic level of 300 ppm at closure of hazardous waste land treatment sites

- the Dutch government (Moen et al., 1985) has adopted soil clean-up guidelines for arsenic of from 30 to 50 ppm

- the Ontario government (OMAF, MOE, MOH, 1986) has established a maximum allowable arsenic level in sludged agricultural soils of 14 ppm.

Recommendation: **soil arsenic concentrations should be <25 ppm for residential redevelopment and <50 ppm for industrial redevelopment.**

* Unless stated otherwise, residential clean-up guidelines also apply to agricultural and parkland situations; while industrial guidelines also apply to commercial situations.

2.3 Cadmium (Cd)

- Cd is toxic to plants and animals and accumulates in mammalian kidney (Bowen, 1979)

- the Phytotoxicology Section "upper limit of normal" cadmium guideline for urban Ontario surface soils is 4 ppm (MOE, 1989a)

- levels of Cd in plant tissue considered to be phytotoxic are: 5-700 ppm (Chaney, 1982); 5-30 ppm (Kabata-Pendias and Pendias, 1984); 8-15 ppm (Davis et al., 1978)

- NAS (1980) has established a maximum dietary Cd concentration chronically tolerated by livestock of 0.5 ppm (based upon Cd residues in animal products used as human food)

- Monenco (1984a) recommended a health-based industrial soil clean-up level for Cd of 8 ppm, based on a regression which predicted a plant tissue Cd level of 0.5 ppm at 8 ppm soil Cd

- Monenco (1984a) recommended a residential soil Cd clean-up guideline of 3.2 ppm, based on a study (Page et al., 1972) which showed that lettuce accumulated 2.5 times more Cd than did barley (8/2.5 = 3.2)

- Kirkpatrick (1981) has stated that Cd levels above 0.1 ppm, fresh weight (equivalent to 0.5 - 2 ppm, dry weight) in fruits and vegetables may pose a potential danger to health from long-term consumption

- Phytotoxicology Section data (unpublished) have revealed that Cd levels in fresh vegetables can occasionally exceed 0.1 ppm if grown in soil containing 2.5 - 4 ppm Cd (some aerial and soil particle contamination is suspected)

- a soil clean-up guideline of 5 ppm Cd has been recommended for home gardens in Great Britain (Smith, 1981)

- Anderson et al. (1983) recommend a maximum soil Cd level of 3 ppm at closure of hazardous waste land treatment sites

- the Dutch government (Moen et al., 1985) has adopted soil clean-up guidelines for Cd of from 5 to 20 ppm

- the Ontario government (OMAF, MOE, MOH, 1986) has established a maximum allowable Cd level in sludged agricultural soils of 1.6 ppm

Recommendation: **soil Cd concentrations should be < 4 ppm for residential redevelopment and < 8 ppm for industrial redevelopment.**

2.4 Chromium (Cr)

- Cr is essential to mammals (Bowen, 1979), and low concentrations appear to be beneficial (though not necessarily essential) to plants (NAS, 1974)

- hexavalent chromium (Cr VI) is particularly toxic to plants and animals (Bowen, 1979)

- the Phytotoxicology Section "upper limit of normal" Cr guideline for urban Ontario surface soils is 50 ppm (MOE, 1989a)

- the predominant form of Cr in soils is trivalent (Cr III) (Kabata- Pendias and Pendias, 1984)

- plant tissue levels of trivalent Cr considered phytotoxic are: 10 ppm (Davis et al., 1978); 20 ppm (Chaney, 1982)

- a Cr III level of 3000 ppm has been established as the maximum dietary concentration chronically tolerated by chickens (NAS, 1980), whereas Davis et al. (1978) report a critical total diet Cr level for livestock of 50 ppm

- the bulk of Cr absorbed by plants concentrates in roots and is poorly translocated to the tops (NRCC, 1976), although translocation of Cr VI appears to be greater than Cr III (Lahouti and Peterson, 1979)

- plants generally will die from phytotoxic effects before they can accumulate amounts of Cr that would be toxic to consumer organisms (NRCC, 1984)

- Monenco (1984a) recommended a soil clean-up guideline for trivalent chromium of 1000 ppm, based upon a literature review which revealed maximum Cr levels of 2.2 ppm and 513 ppm in plants and soil, respectively, and upon the similarity between availability of Cr and Pb in soils

- Monenco (1984b) on the basis of a literature review, concluded that Cr VI can exist in soils and is highly toxic to plants

- the solubility (availability) of Cr VI increases in both acidic and alkaline conditions, but is minimal at pH 5.5 - 8 (Kabata- Pendias and Pendias, 1984)

- soluble Cr VI is normally reduced to insoluble Cr III in soils except in the presence of high oxidized Mn levels (NRCC, 1984; Kabata-Pendias and Pendias, 1984)

- a level of 10 ppm Cr VI in soils has been shown to be phytotoxic to soybeans (Turner and Rust, 1971)

- a soil clean-up level for total Cr of 1000 ppm has been proposed in Great Britain (Smith, 1981)

- Anderson et al. (1983) recommend a maximum soil Cr level of 1000 ppm at closure of hazardous waste land treatment sites

- the Dutch government (Moen et al., 1985) has adopted soil clean-up guidelines for Cr of 250 to 800 ppm

- the Ontario government (OMAF, MOE, MOH, 1986) has established a maximum allowable Cr level in sludged agricultural soils of 120 ppm.

Recommendation: **total soil Cr concentrations should be < 1000 ppm, and hexavalent chromium (Cr VI) concentrations should be < 10 ppm, for both residential and industrial redevelopment.**

2.5 Cobalt (Co)

- Co is essential for animals, man and at least some plants (Bowen, 1979)

- Co is relatively non-toxic to animals and man, and there are no reports of Co toxicity attributable to consumption of natural feedstuffs (Peterson and Girling, 1981)

- although plant species vary widely in Co content, phytotoxicity due to Co is rarely observed in nature (Kabata-Pendias and Pendias, 1984); however, an addition of only 25 ppm Co to soil was reportedly toxic to rice plants (Kabata-Pendias and Pendias, 1984)

- 6 ppm Co in tissue reduced growth of barley (Davis et al., 1978)

- Co deficiency in plants, leading to health effects in grazing animals, is generally of greater concern than an excess of Co (Peterson and Girling, 1981

- the Phytotoxicology Section "upper limit of normal" Co guideline for both urban and rural Ontario surface soils is 25 ppm (MOE, 1989a)

- Bowen (1979) gives a mean Co level in world soils of 8 ppm, and a range of 0.05-65 ppm

- Anderson et al. (1983) recommend a maximum soil Co level of 200 ppm on closure of hazardous waste land treatment sites

- the Dutch government (Moen et al., 1985) has adopted soil

clean-up guidelines for Co of from 50 to 300 ppm

- the Ontario government (OMAF, MOE, MOH, 1986) has established a maximum allowable Co level in sludged agricultural soils of 20 ppm

Recommendation: **soil Co concentrations should be < 50 ppm for residential redevelopment and < 100 ppm for industrial redevelopment.**

2.6 Copper (Cu)

- Cu is an essential element for all organisms (Bowen, 1979)

- the Phytotoxicology Section "upper limit of normal" copper guideline for urban Ontario surface soils in 100 ppm (MOE, 1989a)

- Monenco (1984a) recommended a clean-up level of 330 ppm Cu, based on a regression analysis of Cu levels in plants vs. in soil (330 ppm in soil resulted in the conservative phytotoxic Cu level in vegetation of 25 ppm (Chaney, 1982))

- Davis et al. (1978) have reported a slightly smaller critical Cu level (10% growth reduction) of 20 ppm in barley

- Health and Welfare Canada has established a "maximum residue limit" for fresh fruits and vegetables of 50 ppm Cu (equivalent to 250 - 1000 ppm, dry weight)

- maximum tolerable dietary Cu concentrations for livestock range from 10 ppm (sheep) to 800 ppm (NAS, 1980)

- 300 ppm Cu in soil has been reported to be toxic to citrus (Murphy & Walsh, 1982)

- Anderson et al. (1983) recommend a maximum soil Cu level of 250 ppm at closure of hazardous waste land treatment sites

- the Dutch government (Moen et al., 1985) has adopted soil clean-up guidelines for Cu of from 100 to 500 ppm

- faculty of the University of Guelph Veterinary Science Department have recommended that sheep pasture soils not contain more than 200 ppm Cu (personal communication via the Sludge and Waste Utilization Committee)

- the Ontario government (OMAF, MOE, MOH, 1986) has established a maximum allowable Cu level in sludged agricultural soils of 100 ppm.

Recommendation: **soil Cu concentrations should be < 200 ppm for residential redevelopment (where there is a potential for animal grazing) and < 300 ppm for industrial redevelopment.**

2.7 Lead (Pb)

- Pb is toxic to plants and animals and accumulates in mammalian bone (Bowen, 1979)

- the Phytotoxicology Section "upper limit of normal" lead guideline for urban Ontario surface soils is 500 ppm (MOE, 1989a)

- Monenco (1984a) recommended an industrial soil clean-up guideline for Pb of 1000 ppm, based on a U.S. maximum lead loading for agricultural soils of 1000 ppm

- Monenco (1984a) recommended a residential soil Pb clean-up guideline of 400 ppm, on the basis of a study (John, 1972) showing that lettuce accumulated 2.5 times more lead than did oat shoots (1000/2.5 = 400)

- 400 ppm is also the recommended maximum application of Pb to soils used for growing fruits and vegetables in the U.S. (U.S. EPA, FDA and Dept. of Agric., 1981)

- Kirkpatrick (1981) has expressed the opinion that Pb concentrations higher than 0.5 ppm, fresh weight (equivalent to 2.5 - 10 ppm, dry weight) in fruits and vegetables may pose a potential danger to health from long-term consumption

- the Phytotoxicology Section has found that 0.5 ppm Pb (fresh wt.) in washed vegetables is commonly encountered at soil lead levels of 400 - 500 ppm (some aerial and soil particle contamination is suspected), although there are large variations among plant species and plant parts.

- 500 ppm soil lead was reportedly toxic to tree seedlings (Jaworski, 1979)

- in general, when plants are grown under natural conditions with adequate fertilization and organic matter, soil Pb concentrations of at least 1000 ppm are required before

growth effects are observed (Zimdahl, 1976)

- 35 ppm lead in barley tissue may reduce plant growth (Davis et al., 1978)

- 3 ppm lead in feed is the maximum chronically tolerated by livestock Davis et al., 1978)

- regression analysis (Monenco, 1984a) showed that 3 ppm lead in vegetation is predicted at 520 ppm lead in soil

- the Toronto Department of Public Health (1983) has stated that Pb levels of 1000 ppm or more in soil may pose a risk to the health of young children playing in the soil

- a soil clean-up guideline of 550 ppm Pb has been recommended for home gardens in Great Britain (Smith, 1981)

- Anderson et al. (1983) recommend a maximum soil Pb level of 1000 ppm at closure of hazardous waste land treatment sites

- the Dutch government (Moen et al., 1985) has adopted soil clean-up guidelines for Pb of from 150 to 600 ppm

- the Ontario government (OMAF, MOE, MOH, 1986) has established a maximum allowable Pb level in sludged agricultural soils of 60 ppm

Recommendation: **soil Pb concentrations should be < 500 ppm for residential redevelopment and < 1000 ppm for industrial redevelopment.**

Note - The above clean-up guidelines for lead have been endorsed by the Royal Society of Canada Commission on Lead in the Environment (Royal Society, 1986)

2.8 Mercury (Hg)

- Hg is very toxic to plants and animals and accumulates in mammalian kidney (Bowen, 1979)

- the Phytotoxicology Section "upper limit of normal" Hg guideline for urban Ontario surface soils is 0.5 ppm (MOE, 1989a)

- levels of Hg in plant tissue considered to be phytotoxic are: 3-6 ppm (Davis et al., 1978); 1-3 ppm (Kabata-Pendias

and Pendias, 1984)

- Monenco (1984a) initially recommended a clean-up guideline (residential and industrial) of 2 ppm Hg, based on a literature review which revealed a maximum plant Hg level of 0.5 ppm at a soil Hg level of 2 ppm

- Davis et al. (1978) report a critical mercury level in livestock feed of 1 ppm, whereas the NAS (1980) as set a maximum tolerable concentration of mercury for domestic animal feed of 2 ppm

- Kirkpatrick (1981) has stated that Hg levels above 0.05 ppm, fresh weight (equivalent to 0.25 - 1 ppm, dry weight) in fruits and vegetables may pose a potential danger to health from long-term consumption

- Phytotoxicology Section investigations (unpublished results) have revealed that Hg concentrations in garden vegetables do not exceed 0.05 ppm (fresh wt.) at soil Hg levels up to 2 ppm, unless an aerial Hg source is present

- the Phytotoxicology Section expressed the concern that children with pica might be affected at soil mercury levels below 2 ppm

- based on worst case assessment (assuming 100% methyl mercury) of potential danger to children from ingesting mercury-contaminated soil, Monenco Consultants recommended a residential Hg clean-up criterion of 1 ppm (Monenco, 1984b)

- Bashor and Turri (1986) calculated an allowable concentration of mercury in soil of 12 ppm, assuming 1% (0.12 ppm) organic mercury

- a soil clean-up guideline of 1.5 ppm Hg has been recommended for home gardens in Great Britain (Smith, 1981)

- Anderson et al. (1983) recommend a maximum soil Hg level of 9 ppm at closure of hazardous waste land treatment sites

- the Dutch government (Moen et al., 1985) has adopted soil clean-up guidelines for Hg of 2 to 10 ppm

- the Ontario government (OMAF, MOE, MOH, 1986) has established a maximum allowable Hg level in sludged agricultural soils of 0.5 ppm

Recommendation: **soil Hg concentrations should be < 1 ppm for residential redevelopment and < 2 ppm for industrial redevelopment.**

2.9 Molybdenum (Mo)

- Mo is a essential element for all organisms (Bowen, 1979)
- the Phytotoxicology Section "upper limit of normal" molybdenum guideline for urban Ontario surface soils is 3 ppm (MOE, 1989a)
- Monenco (1984b) recommended a soil clean-up level for Mo of 40 ppm, based on potential phytotoxicity
- 135 ppm Mo in plant tissue was reported to be toxic to barley (Davis et al., 1978)
- there is generally a poor relationship between total Mo content in soils and in vegetation (Monenco, 1984b)
- molybdenum-induced copper deficiency (molybdenosis) may occur in animals consuming vegetation with elevated (10 - 20 ppm) Mo concentrations (Tolle and Arthur, 1983; Chappell and Petersen, 1977)
- soils containing 5 ppm Mo or more may support herbage containing elevated Mo levels, resulting in molybdenosis (Thornton, 1981)
- the maximum dietary Mo concentration chronically tolerated by domestic livestock ranges from 5 to 100 ppm (NAS, 1980)
- Anderson et al. (1983) recommend a maximum soil Mo level of 5 ppm at closure of hazardous waste land treatment sites
- the Dutch government (Moen et al., 1985) has adopted soil clean-up guidelines for Mo of from 40 to 200 ppm
- the Ontario government (OMAF, MOE, MOH, 1986) has established a maximum allowable Mo level in sludged agricultural soils of 4 ppm

Recommendation: **soil Mo concentrations should be < 5 ppm for residential redevelopment (where there is a possibility that vegetation may be consumed by livestock), and < 40 ppm for industrial redevelopment.**

2.10 Nickel (Ni)

- Ni is essential to some plants and all vertebrates (Bowen, 1979)

- the Phytotoxicology Section "upper limit of normal" Ni guideline for urban Ontario surface soils is 60 ppm (MOE, 1989a)

- Monenco (1984a) recommended a soil clean-up level for Ni of 200 ppm, which was twice the U.S. suggested maximum Ni loading of 100 ppm for a fine-textured soil

- 50 ppm Ni is the maximum dietary concentration chronically tolerated by livestock (Davis et al., 1978; NAS, 1980)

- Davis et al. (1978) cite toxic levels of Ni in plant tissue ranging from 11 to 147 ppm

- 266 ppm Ni in soil (88 ppm in oat plants) resulted in moderate chlorosis and stunting in oats (Anderson et al., 1973)

- Monenco (1984a) reported a maximum plant tissue Ni level of 3.2 ppm at a soil Ni level of 60 ppm; assuming a linear relationship, a plant tissue level of 11 ppm Ni (minimum phytotoxic level) could result from a soil concentration of 206 ppm Ni

- Anderson et al. (1983) recommend a maximum soil Ni level of 100 ppm at closure of hazardous waste land treatment sites

- the Dutch government (Moen et al., 1985) has adopted soil clean-up guidelines for Ni of from 100 to 500 ppm

- the Ontario government (OMAF, MOE, MOH, 1986) has established a maximum allowable Ni level in sludged agricultural soils of 32 ppm

Recommendation: **soil Ni concentrations should be < 200 ppm for both residential and industrial redevelopment.**

2.11 Selenium (Se)

- Se is essential to some plants and all vertebrates (Bowen, 1979)

- the Phytotoxicology Section "upper limit of normal" Se guideline for urban Ontario surface soils is 2 ppm (MOE, 1989a)

- no instances of Se phytotoxicity have been reported in the field (Kabata-Pendias and Pendias, 1984)

- Davis et al. (1978) report that 30 ppm Se in plant tissue was toxic to barley, while Chaney (1982) reports a phytotoxic tissue Se level of 100 ppm

- Marier and Jaworski (1983) state that Se injury to crop plants can occur at tissue concentrations of > 300 ppm

- rye grass growth was reduced at a Se application rate of 10 kg/ha (equivalent to approximately 5 ppm in surface soil) (Anderson et al., 1983)

- selenium is toxic to livestock, and the difference between essential and toxic levels in animals feed is quite small (Kabata-Pendias and Pendias, 1984)

- Davis et al. (1978) cite 5 ppm Se as the critical total diet level for livestock, whereas NAS (1980) has established 2 ppm Se as the maximum dietary level chronically tolerated by swine and chickens

- although total soil Se has been reported to give a better measure of plant response than do its soluble fractions (Kabata-Pendias and Pendias, 1984), most studies covering a wide range of soil types illustrate the lack of a correlation between total soil and plant Se content (Peterson et al., 1981)

- soils containing more than 0.5 ppm of total selenium can produce herbage containing 4 - 5 ppm Se or more, and are therefore, regarded as potentially dangerous to livestock (Underwood, 1971)

- Anderson et al. (1983) recommend a maximum soil Se level of 5 ppm at closure of hazardous waste land treatment sites

- the Ontario government (OMAF, MOE, MOH, 1986) has established a maximum allowable Se level in sludged agricultural soils of 1.6 ppm

Recommendation: **soil Se concentrations should be < 2 ppm for residential redevelopment (where there is a possibility that vegetation may be consumed by livestock), and < 10 ppm for industrial redevelopment**

2.12 Silver (Ag)

- Ag is very toxic to plants but is much less toxic to mammals (Bowen, 1979)
- the Phytotoxicology Section has not developed an "upper limit of normal" guideline for Ag in Ontario soils
- mean levels of Ag in soil are reported as 0.05 ppm (Bowen, 1979) and 1 ppm (Brooks, 1972), with ranges of 0.01 - 5 ppm (Peterson and Girling, 1981) and 0.01 - 8 ppm (Bowen, 1979)
- although soluble silver compounds are highly toxic, Ag apparently is essentially immobile (unavailable) in soils at pH > 4 (Kabata- Pendias and Pendias, 1984)
- however, there is a relationship between Ag in many plant species and in soil (Kabata-Pendias and Pendias, 1984)
- Monenco (1984b) recommended a soil clean-up guideline of 100 ppm Ag based on potential phytotoxicity
- plant tissue Ag levels of 5 ppm in bush beans (cited in Kabata- Pendias and Pendias, 1984) and 4 ppm in barley (Davis et al., 1978) resulted in reduced yields
- based on a logarithmic regression calculated from information provided by Monenco (1984b), 4 ppm Ag in plant tissue is predicted at 50 ppm Ag in soil (AgI studies excluded because AgI has extremely low water solubility)
- 28 pm Ag (added to soil as AgI [in organic solvent]) reduced emergence of lodgepole pine (cited in Monenco, 1984b)
- Anderson et al. (1983) suggest a maximum soil Ag level of 90 ppm at closure of hazardous waste land treatment sites

Recommendation: **soil Ag concentrations should be < 25 ppm for residential redevelopment and < 50 ppm for industrial redevelopment.**

2.13 Zinc (Zn)

- Zn is an essential element for all organisms (Bowen, 1979)
- the Phytotoxicology Section "upper limit of normal" zinc guideline for urban Ontario surface soils is 500 ppm (MOE, 1989a)
- Monenco (1984a) recommended a soil clean-up guideline for Zn of 1000 ppm, based on a literature review which revealed a plant Zn level of 130 ppm at a soil Zn level of 1000 ppm
- Davis et al. (1978) cite phytotoxic tissue Zn levels of from 200 to 400 ppm
- Collins (1981) cites studies reporting that 60 and 81 ppm Zn in wheat and corn tissue, respectively, were phytotoxic
- based on a regression analysis of Zn levels in plants vs. in soil (Monenco, 1984a), the predicted soil Zn concentration corresponding to a plant Zn level of 60 ppm is 410 ppm
- the tolerance of domestic livestock to Zn in animal feed ranges from 300-1000 ppm (NAS, 1980)
- Anderson et al. (1983) recommend a maximum soil Zn level of 500 ppm at closure of hazardous waste land treatment sites
- the Dutch government (Moen et al., 1985) has adopted soil clean-up guidelines for Zn of from 500 to 3000 ppm
- the Ontario government (OMAF, MOE, MOH, 1986) has established a maximum allowable Zn level in sludged agricultural soils of 220 ppm

Recommendation: **soil Zn concentrations should be < 800 ppm for both residential and industrial redevelopment**

2.14 Nitrogen (N)

- N is an essential element for all organisms (Bowen, 1979)
- the Phytotoxicology Section has not developed an "upper limit of normal" guideline for N in Ontario soils

- average N content of world soils is 0.2%, with a "normal" range of 0.02-0.5% (Bowen, 1979)

- excessive soil N may be a concern where large amounts of nitrogen have been added to soil, such as in petroleum sludge land-farming areas

- N is an essential macronutrient for plant growth, but high soil levels may represent over-fertilization which can lead to excessive vegetative growth and adversely affect fruit and grain quality (Brady, 1974)

- N in soils is mainly tied up in unavailable organic forms (Brady, 1974), but rapid mineralization of N (which could occur if certain conditions are met) would result in liberation of ammonia and nitrate nitrogen, possibly leading to groundwater contamination and accumulation of toxic nitrate levels in plants (Parker and Sommers, 1983)

- if the carbon-nitrogen ratio in soil is greater than 12:1, it is unlikely that mineralization would be excessively rapid (Bates, 1986).

Recommendation: **if total soil N levels exceed 0.5% (residential redevelopment) or 0.6% (industrial redevelopment), an evaluation of the mineralization potential of the soils should be undertaken (Monenco, 1984a).**

2.15 Oil and Grease

- Monenco Consultants (1984a) recommended a soil clean-up level for oil and grease of 2%, based on potential phytotoxicity

- most studies (reviewed by Emerson (1983), and Monenco (1984a & b)) indicate that the critical level for plant growth is approximately 1% oil and grease in soil

- however, as Monenco (1984a & b) point out, these controlled studies employed fresh crude oil or refined products, whereas the most phytotoxic compounds (the lighter ends) are lost through volatilization and/or biodegradation in the field (cf. Emerson, 1983)

- therefore, where oil is known to have been "weathered" on site for a reasonable period of time, a clean-up level

greater than 1% oil and grease could be allowed while still precluding phytotoxicity

Recommendation: **oil and grease concentrations in soil should not exceed 1% for fresh oil and 2% for weathered oil (minimum 2 yr. exposure on site), for both industrial and residential redevelopment.**

Note - While these oil and grease clean-up levels will prevent significant toxic effects on plants, the possibility exists that certain hydrocarbon components may be present at levels potentially harmful to human health. This danger should be addressed, with input from health authorities, on a case by case basis. Analyses for individual toxic organic compounds or groups of compounds may be justified. Also, excessive odour may, in some cases, result in a requirement for soil clean-up at oil and grease levels lower than 1%.

2.16 Electrical Conductivity (EC)

- Monenco Consultants (1984a & 1984b) recommended a soil clean-up guideline for EC of 4 mS/cm, based on potential phytotoxicity
- growth of very sensitive plant species (clover, beans, onions, carrots, some fruit trees) may be inhibited at soil conductivities (saturation extract) as low as 2 mS/cm (Bernstein, 1975)
- growth of most plant species is inhibited at soil conductivities above 4 mS/cm (Bernstein, 1975)
- EC is reduced with time due to leaching by precipitation

Recommendation: **electrical conductivity (mS/cm) of soil saturation extract should be < 2 for residential redevelopment and < 4 for industrial redevelopment.**

2.17 Sodium Adsorption Ratio (SAR)

- SAR = $Na^{+}/[(Ca^{+2} + Mg^{+2})/2]^{1/2}$, where concentrations are in soil solution in meq/1.

- Monenco Consultants (1984a) recommended a soil clean-up criterion for SAR of 15, based upon adverse effects on permeability and structural stability of soil

- at SAR values >5, water penetration can be reduced and soil structure may deteriorate (Fuller and Warrick, 1985).

- a guideline established by the University of Guelph states that wastes with an SAR >5 should not be added to the soil (Bates, 1986)

- SAR values > 12 are indicative of sodic soils, and growth of non-tolerant plant species may be restricted (Richards, 1954; Brown et al., 1985).

- nutritional effects due to inability of non-tolerant plants to absorb adequate amounts of Ca and Mg may occur at SAR's > 10, although most crops are affected nutritionally at SAR's of about 25 (Bernstein, 1975)

Recommendation: **SAR of soil solution should be < 5 for residential redevelopment and < 12 for industrial redevelopment.**

3 RATIONALES FOR PROVISIONAL GUIDELINES

3.1 Antimony (Sb)

- Sb is not essential for animals or plants (Kabata-Pendias and Pendias, 1984)
- although soluble forms of Sb are readily taken up by plants, there are no reports of Sb phytotoxicity in the field (Kabata-Pendias and Pendias, 1984)
- the Phytotoxicology Section "upper limit of normal" Sb level in urban Ontario surface soils in 8 ppm (MOE, 1989a)
- Bowen (1979) gives a mean Sb concentration for world soils of 1 ppm and a range of 0.2 - 10 ppm
- Anderson et al. (1983) suggest a maximum soil Sb level of 225 ppm on closure of hazardous waste land treatment sites

Recommendation: **soil Sb concentrations should be < 25 ppm for residential redevelopment and < 50 ppm for industrial redevelopment.**

3.2 Barium (Ba)

- Ba may be essential to mammals (Bowen, 1979), but apparently is not essential to plants (Kabata-Pendias and Pendias, 1984)
- some forms of Ba may be toxic to man (personal communication, J. Stopps, Min. of Labour)
- Ba is mobile in acid soils and is readily taken up by plants (Kabata-Pendias and Pendias, 1984)
- concentrations of 1% (10,000 ppm) Ba in plants may be highly phytotoxic (Kabata-Pendias and Pendias, 1984)
- 500 ppm Ba in tissue reduced growth of barley (Davis et al., 1978)

- the Phytotoxicology Section has not established an "upper limit of normal" guideline for Ba in Ontario soils

- Bowen (1979) gives a mean level for Ba in world soils of 500 ppm, with a range of 100 - 3000 ppm

- in view of the relatively high concentrations of Ba in plants and soils, and the lack of information about its physiological effects, more research on this relatively inert element is required (Peterson and Girling, 1981)

- Anderson et al. (1983) suggest a maximum soil Ba level of 450 ppm on closure of hazardous waste land treatment sites

- the Dutch government (Moen et al., 1985) has adopted soil clean-up guidelines for Ba of from 400 to 2000 ppm

Recommendation: **soil Ba concentrations should be < 1000 ppm for residential redevelopment and < 2000 ppm for industrial redevelopment.**

3.3 Beryllium (Be)

- Be is not known to be essential to mammals (Bowen, 1979), and apparently is not essential to plants (Kabata-Pendias and Pendias, 1984)

- Be is potentially phytotoxic, particularly in acid soils (Peterson and Girling, 1981)

- toxic concentrations of Be in plants generally range from 10 to 50 ppm, while 2 to 16 ppm Be in solution may be highly phytotoxic (Kabata-Pendias and Pendias, 1984)

- only 0.6 ppm Be in tissue reduced growth of barley (Davis et al., 1978)

- there is no evidence that existing levels of Be in food plants pose a health risk to man, but more data are needed (Kabata-Pendias and Pendias, 1984)

- the Phytotoxicology Section has not established an "upper limit of normal" guideline for Be in Ontario soils

- Bowen (1979) gives a mean level for Be in world soils of 0.3 ppm, with a range of 0.01 - 40 ppm

- Anderson et al. (1983) recommend a maximum soil Be level of 50 ppm at closure of hazardous waste land treatment sites

Recommendation: **soil Be concentrations should be < 5 ppm for residential redevelopment and < 10 ppm for industrial redevelopment.**

3.4 Vanadium (V)

- V is essential to animals, man and at least some plants (Bowen, 1979)
- concentrations of soluble (available) V ranging from 10 to 140 ppm are reportedly phytotoxic under experimental conditions (Peterson and Girling, 1981)
- however, there are no reports of V phytotoxicity in the field (Kabata-Pendias and Pendias, 1984)
- V added at a rate of 50 - 100 ppm to conifer forest soils reduced acid phosphatase activity (Peterson and Girling, 1981)
- pronounced differences in V content among plants have been reported, which may reflect both analytical difficulties and pollution (Kabata-Pendias and Pendias, 1984)
- 2 ppm V in tissue reduced growth of barley (Davis et al., 1978)
- the Phytotoxicology Section "upper limit of normal" guideline for V in urban Ontario surface soils is 70 ppm (MOE, 1989a)
- Bowen (1979) gives a mean level for V in world soils of 90 ppm, with a range of 3 - 500 ppm
- further studies into the environmental behaviour of V are warranted (Peterson and Girling, 1981)
- Anderson et al. (1983) recommend a maximum soil V level of 500 ppm on closure of hazardous waste land treatment sites

Recommendation: **soil V concentrations should be < 250 ppm for both residential and industrial redevelopment.**

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6 TABLES

Table 1: Clean-up Guidelines for Soils

Parameter[b]	Criteria for Proposed Land Use[a,c]			
	Residential/Parkland/ Agricultural[d]		Commercial/Industrial	
	Medium & Fine Textured Soils	Coarse Textured Soils[e]	Medium & Fine Textured Soils	Coarse Textured Soils[e]
pH (recommended range)	6-8	6-8	6-8	6-8
EC (mS/cm)[h]	2	2	4	4
SAR[i]	5	5	12	12
Arsenic	25	20	50	40
Cadmium	4[a1]	3[a1]	8[a1]	6[a1]
Chromium (VI)	10	8	10	8
Chromium (total)	1000	750	1000	750
Cobalt	50	40	100	80
Copper	200[a2]	150[a2]	300	225
Lead	500[a1]	375[a1]	1000[a1]	750[a1]
Mercury	1[a1]	0.8[a1]	2[a1]	1.5[a1]
Molybdenum	5[a2]	5[a2]	40	40
Nickel	200	150	200	150
Nitrogen (%)	0.5[f]	0.5[f]	0.6[f]	0.6[f]
Oil and Grease (%)	1[g]	1[g]	1[g]	1[g]
Selenium	2[a2]	2[a2]	10	10
Silver	25	20	50	40
Zinc	800	600	800	600

a. Clean-up guidelines recommended by the Phytotoxicology Section, Air Resources Branch, Ministry of the Environment. The guidelines are based primarily on phytotoxicity, except for (a^1), based on human health, and (a^2), based on health of grazing animals.

b. All units are in ppm (ug/g), dry weight, unless otherwise stated.

c. For comparison with these guidelines, analyses for metals and metalloids must be conducted using an approved strong, mixed-acid digestion procedure. Contact the

Laboratory Services Branch of MOE if in doubt about acceptable methods.

d. Guidelines have been endorsed by the OMAF/MOE/MOH Sludge and Waste Utilization Committee.

e. Defined as greater than 70% sand and less than 17% organic matter.

f. If N levels exceed the guidelines, the mineralization potential of the soils should be evaluated. Additions of N-based fertilizer may be counter-productive.

g. Guideline given is for fresh oil; for weathered oil (min. 2 yr. exposed on site), the guideline is 2%.

h. EC = electrical conductivity (saturation extract).

i. SAR = sodium adsorption ratio

Table 2: Provisional Clean-up Guidelines for Soils

Parameter[b]	Criteria for Proposed Land Use[a,c,d]			
	Residential/Parkland/ Agricultural[e]		Commercial/Industrial	
	Medium & Fine Textured Soils	Coarse Textured Soils[f]	Medium & Fine Textured Soils	Coarse Textured Soils[f]
Antimony	25	20	50	40
Barium	1000	750	2000	1500
Beryllium	5	4	10	8
Vanadium	250	200	250	200

a. These guidelines are tentative; actual permissible levels contaminants may vary according to site-specific circumstances. Further information on the application of these guidelines may be obtained from the Phytotoxicology Section of the Air Resources Branch, Ministry of the Environment.

b. All units are in ppm (ug/g), dry weight.

c. For comparison with these guidelines, analyses must be conducted using an approved strong, mixed-acid digestion procedure. Contact the Laboratory Services Branch of MOE if in doubt about acceptable methods.

d. These provisional guidelines apply to soil of minimum pH 6.

e. Guidelines have been endorsed by the OMAF/MOE/MOH Sludge and Waste Utilization Committee.

f. Defined as greater than 70% sand and less than 17% organic matter.

7 APPENDICES

Appendix 1: Definition of "Guideline" and "Provisional Guideline"

A "guideline" in use by the Ontario Ministry of the Environment represents a value developed for application in abatement action, site restoration or the granting of conditional Certificates of Approval. A guideline is less enforceable than a "standard" in that the latter is approved by Cabinet and is officially published in the Ontario Gazette. In any appeal action of a Director's Order, or denial of a Certificate of Approval, the applicability of a guideline may be questioned, whereas a standard is not open to question.

A "provisional guideline" has the same general applicability as a guideline, but due to a lack of definitive data, is regarded as having a less sound basis and is therefore somewhat less defensible. As in the case of a guideline, in any appeal action, the applicability of a provisional guideline may be questioned.

Appendix 2: Interactive Effects of Contaminants in Soil

The question of interactive effects of contaminants in soil, with regard to phytotoxicity, is extremely complex. Limited studies that have been conducted on interactions between two or three substances in soil have demonstrated that such effects may be antagonistic (e.g. the role of soil phosphorus in reducing lead uptake by plants), additive (e.g. the phytotoxicity of Cu, Ni and Zn to barley) or synergistic (more than additive) (e.g. the phytotoxicity of Cd and Pb). However, there are many variables that determine the nature and extent of such interactions, including plant species, soil type, pH, fertility status and both relative and absolute concentrations of the

contaminants (e.g. the toxic effects of Cu and Zn in barley, though normally additive, are antagonistic when tissue concentrations of both are above their critical levels).

The complexity of the possible interactions increases greatly when many contaminants co-exist. It is therefore impractical, if not impossible, to conduct meaningful studies on the nature of these very complex interactions in soil and plants. In any event, application of results from such studies would be restricted to a very specific range of conditions, and development and enforcement of guidelines based on potential interactions would pose an enormous logistical problem.

All this is not to say that the question of contaminant interactions should be completely ignored in determining clean-up action. Although there are insufficient conclusive experimental data at present to justify establishing additional clean-up levels for any one contaminant based on the concentration of other contaminants, the possibility of additive and synergistic interactions should always be considered by the regulatory agency. For example, it might be deemed inadvisable to allow the presence of a large number of contaminants together on a site at concentrations at or near the clean-up levels, particularly where there is evidence of synergism for some of the contaminants in question. However, it is stressed that this can only be addressed on a site-specific basis. In reality, due to the generally conservative nature of the guideline setting process, interactive effects are not likely to be significant, in terms of phytotoxicity, at soil concentrations below the recommended clean-up levels.